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Analyses of Parameters Affecting Helicopter Timber Extraction

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ABSTRACT

In the last 25 years, helicopter extraction of timber has developed as an important harvesting alternative in mountainous areas. Typical helicopter operations include the extraction of valuable timber from stands with inadequate road networks, large areas of difficult to reach wind-throw, and sensitive sites where the negative impact on soil and water must be minimized. An empirical study provides information on the effect of silvicultural treatment and pilot experience on the productivity of the K-Max helicopter. The productivity model is a function of the average stem piece size, the horizontal distance between stump and landing, the silvicultural treatment, and the experience of the pilot. The productivity obtained when harvesting from a clear-cut was greater than from the 'femel-cut' (patch-cut) extraction site by 0.20 m^3/min, or 21% at an average piece size of 1.5 m^3. The inexperienced helicopter pilot had timber extraction experience but just 30 flight hours on the K-Max while the experienced pilot had 22,000 K-Max flight hours. The experienced pilot yielded a 0.37 m^3/min increase in productivity, which is a 63% increase at an average piece size of 1.5 m^3. This indicates that operator experience on a particular machine may be very important when comparing harvesting systems based on time studies.

Keywords: *Timber extraction, helicopter, K-Max, productivity model, silvicultural system, learning-curve effect, operator experience, pilot experience, patch cut, clear-cut, Austria.*

INTRODUCTION

In the last 25 years helicopter extraction of timber has developed as an important harvesting alternative in mountainous areas. Helicopters compete on economic and environmental terms particularly in stands with valuable timber and an absence of adequate road networks. The use of helicopters, in comparison to other harvesting methods, allows the negative impact such as erosion or compaction of soil and sedimentation to waterways to be minimized [1]. They can also be used on sensitive sites [14]. The high productivity of a helicopter also allows it to harvest wind-throw areas quickly [17].

In the initial phases of helicopter extraction, emphasis was placed on directional felling and pre-bunching of stems to improve productivity [4]. Possible methods for stem weight estimation [7, 8] and improving payload utilization above the typical 60-80% [e.g. 7, 14, 11] were studied. Optimizing payload increases the risks of overloading; forcing the pilot to abort the load and fly to another pick-up point as well as having a negative impact on the maintenance schedule. In recent times more double-load hooks have been used which allow the pilot to release part of the load if the initial load exceeds the maximum allowable payload [15].

In Europe, the trend towards more uneven-aged forest management has resulted in greatly reduced harvest areas and an increase in single-tree extraction. Case studies on the impact of various silvicultural treatments on productivity found the lower timber volume per harvest area to be a critical parameter [15]. This is especially true for European mountainous conditions.

The helicopter 'K-Max' was specifically designed for carrying external loads and has much promise for the commercially viable extraction of smaller timber volumes [18]. The goal of this study is to establish a productivity model for the K-Max helicopter based on silvicultural treatment and the experience of the pilot.

While the influence on helicopter productivity of different extraction options, terrain and stand parameters has been intensively quantified; there are no systematic studies on the influence of pilot experience. Knowledge about pilot experience is especially relevant when comparing productivity. Sloan *et al.* [18] indicated poor productivity from timber extraction using a K-Max was related to lack of pilot experience with a new helicopter (learning-curve effect). The learning-curve effect that an operator displays over time has been shown for cable yarder operators and choker-setters [9, 16, 5] as well as harvester and forwarder operators [16]. This project used a case study approach to assess the role of operator experience, silviculture system, terrain and site variables and return trip loading on machine productivity.

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METHODOLOGY

Model Hypothesis

The productivity of helicopter timber extraction depends upon the average stem volume to be extracted and the vertical and horizontal extraction distance [12]. Cycles times where the bunches of chokers are returned to the stump takes longer than when the outgoing flight is 'empty'. Krag and Clark [15] showed the effect of silvicultural treatment on the helicopter productivity in a Canadian study: the smaller the harvest area the longer the average cycle time. The possible impact of the experience of the helicopter pilot has been identified [e.g. 12, 18] but never quantified. On the basis of these considerations the following helicopter extraction model hypothesis was developed (Equation 1).

$$PROD_{k\,max} = ¦\,(stemvol, hord, verd, TREAT, PILOT, CHOK) \quad (1)$$

Where:

$PROD_{kmax}$	=	Machine productivity K-Max
Stemvol	=	Average stem piece size per cycle
hord	=	Horizontal distance
verd	=	Vertical distance
TREAT	=	Silvicultural system
PILOT	=	Experience of the helicopter pilot
CHOK	=	Return flight with choker

Harvesting System

The harvesting process had three separate components. The same two forestry workers carried out the chainsaw felling and delimbing of the trees at both sites. Felling pattern is important for creating an optimal payload. The few trees that had a DBH greater than 55 cm were bucked (if possible) to avoid a possible overloading of the helicopter. The trees were felled well in advance of the extraction to allow a natural timber drying process to take place.

A professional helicopter crew carried out the extraction of the stems. Three or four choker-setters prepared the turns, taking care to optimize the payload of the helicopter without exceeding the maximum allowable payload. The helicopter used was a Kaman K-1200 K-Max (Table 1). This helicopter has been specifically designed for the transport of external loads with a maximum payload capacity of 27 kN. Two overlapping rotors eliminate the turning moment at the rear, so that no tail rotor is required.

The shape and location of both landings minimized the time the helicopter needed for approach and departure, the pilot had a clear view of the ground crew, and the safety of the ground crew was maintained. The two chasers at the landing provided guidance for the pilot to release the turn and preparing bunches of chokers to return to the stump. A mechanic was also on site for to servicing and refueling the helicopter.

The final work process was finishing the delimbing and bucking of the stems into logs, for which two forestry workers with chainsaws and one skidder were used.

Table 1: Technical Data for the Helicopter K-MAX.

Description	
Engine	Allied Signal T5317 A-1
Power	1,102 kW
Fuel – Kerosene	325 Jet A1
Rotor diameter	14.70 m
Rotor system	Twin-rotors
Total height	4.14 m
Total length	15.85 m
Max. Start weight	52 kN
Tare weight (without fuel)	22.5 kN
Maximum: Payload	27 kN
Maximum: Distance	420 km
Maximum: Flight period	2.5 h
Travel speed	175 km/h
Maximum Climbing ability	162 m/min
Approximate Price	US$900,000.

Study Sites

Two different harvest sites were chosen to measure helicopter extraction productivity. One site was a femel-cut (patch-cut) site with seven areas of 0.25 – 0.35 ha and one clear-cut site with 1.06 ha (Table 2). Femel-cut is a silvicultural regeneration system for mixed spruce and larch stands. Regeneration is initiated by spot wise shelterwood cuts (approximate diameter of spots is 30-40 m depending on stand height, slope and aspect). After establishment of regeneration (shade tolerant species) the shelter is removed and the spots are radially enlarged (favoring shade intolerant species) and new spots initiated. This procedure results in a structured multi-species stand and can be combined with artificial regeneration.

It should also be noted that a clear-cut in the European realm typically refers to areas of approximately 1 to 2 hectares. In North America, helicopter clear-cuts are in the range of 20 to 100 hectares [e.g., 14, 15].

Table 2: Stand description.

	Femel-cut area	Clear-cut area
Location	Trofaiach, Austria	Lainsach, Austria
Height above sea level (m)	1225	1300
Bedrock	Limestone	Gneis
Terrain	flat	rolling
Area (ha)	0.25 – 0.35	1.06
Slope (%)	50	60
Terrain trafficability	average to poor	poor
Volume removed (m^3)	516	742
Stand age (years)	150	170
Stand composition (basal area)	60% Spruce / 40% Larch	40% Spruce / 60% Larch

Data Collection

The flight cycle was used as the observation unit. For data collection, two people were required. The K-Max has an integrated GPS system and data capture computer for recording cycle time. However, previous problems with data capture reliability meant that for this study one person used the Latschbacher time study computer on the ground to collect machine data while the other was responsible for recording operational variables such as stem dimensions. The physical parameters and time elements recorded are presented in Table 3.

The pilot gave the payload weight for each cycle over the radio. After the extraction was completed a tree species-specific weight to volume factor was calculated. From the total weight of the payload, the species-specific weight to volume factor and the number of stems per cycle, the average stem piece size could be determined. The horizontal and vertical flight distances were measured on a map and, in the clear-cut, the harvest area was divided into quadrants to obtain an improved estimation of the extraction distance.

Survey Layout

A factorial layout was used to test the model hypothesis. Table 3 shows three factors, with two levels, hence a 2^3-study layout. A balanced layout would require a similar cell frequency, which in this case (as with most empirical studies) cannot be satisfied (Table 4). The study layout is therefore unbalanced, which is typical for forestry productivity studies since under real conditions a variation in factors can only be carried out in limited format. For this helicopter study, every fourth cycle the helicopter had to return a set of chokers to the forest area and femel-cut and clear-cut operations could not be conducted in the same stand. To the extent possible, an attempt was made to keep stand, terrain and weather conditions the same for the two stands during extraction.

The same helicopter was used for all the operations, and the experienced and inexperienced pilot alternated. Experience in this study is only defined in terms of previous flying hours; the pilots' hand-eye coordination, physique or motivation was not tested. Both pilots flew in the morning and afternoon (their work schedule was randomized). The operator changeover always took place during re-fuelling. This is why the experienced pilot had a higher number of cycles in the cells of the layout.

Statistical Analyses

Variance analysis attempts to quantify the influence of nominal or ordinal-scaled variables. The following analyses were carried out with S-Plus, the statistical fundamentals of which are described in Venables and Ripley [21]. For each part of the model, the following analysis strategy was chosen [13, 19]:

- developing a linear model with all the co-variables and factors (Table 3);
- evaluating the non-linearity of the co-variables;
- choosing a number of sub-models through the removal of non-significant variables;
- choose two-way interactions of the sub-models.

Tree volume is a major part of all production functions but the relationship between productivity and tree volume is rarely linear [6]. Therefore a power factor is used on the co-variable *stemvol*. Häberle [6] recommends the estimation of this power value with an iterative procedure. Box and Cox [2] describe a method whereby the optimal transformation is carried out using a maximum likelihood function. Venables and Ripley [21] show how such a Box-Cox transformation procedure can be carried out in S-Plus. Similarly, this principle of the maximum likelihood function can also be used on the independent co-variables [10].

Table 3. Description of the individual physical parameters and time elements.

Type	Name	Description	Unit
Dependent-Variables	cycle	Total time for one flight cycle. Productive System hours	min
	loadvol	Total payload for a single flight cycle	m^3
	$prod_{kmax}$	(loadvol/cycle)	m^3/min
Factors	TREAT	Silvicultural system: (0) femel-cut and (1) clear-cut	2 levels
	PILOT	Pilot's K-Max experience: (0) inexperienced Pilot (30 K-Max flight hours) and (1) experienced Pilot (22,000 K-Max flight hours)	2 levels
	CHOK	Return flight with chokers: (0) no and (1) yes	2 levels
Co-variables	stemvol	Average stem piece size per cycle	m^3
	piece	Number of stems per load	n
	hord	Horizontal distance from stump to landing	m
	verd	Vertical distance from stump to landing	m
Times	PSH_0	Productive system hours. All time components that are directly necessary for completing the timber extraction work task	min
	fueling	Time for approach and departure from fueling station and fueling itself	min

Table 4. Study layout.

	Femel-cut (63 choker-cycles)	Clear-cut (96 choker-cycles)	Total Cycles (159 choker-cycles)
Experienced K-Max Pilot (100 choker-cycles)	45, 79, 46	100, 96, 37	403
Inexperienced K-Max Pilot (59 choker-cycles)	27, 40, 27	47, 47, 34	222
Total Cycles (159 choker-cycles)	264	361	625

Subsequently, using multiple linear regressions, the parameters of the model are estimated, with which the productivity of the helicopter K-Max under given conditions can best be quantified.

RESULTS AND DISCUSSION

Summary Statistics

A summary of the results is presented in Table 5. The average cycle time is approximately three minutes. A flight cycle that returns the chokers to the stump takes 20-25% longer than a normal flight cycle [11]. The average payload extracted was approximately 20 kN and translates to an approximate volume of 2 m^3. Considering the maximum allowable payload of 27 kN, this is equivalent to 74% utilization. This value is in the range of common helicopter payload utilization rates of 60-80%. However , it indicates possible productivity increases through payload building optimization. Average horizontal distances of 700 m and vertical distances of 220 m are in the realm of economically viable flight distances. The fueling of the helicopter took approximately 7-10 minutes and a full tank

(300 l Kerosene) lasted about an hour.

Table 5. Breakdown of summary statistics.

Variable[1]	Mean	0.05 Quantile	0.95 Quantile	Unit
cycle	2.96	1.76	5.40	min
fueling	8.55	4.44	16.96	min
loadvol	20.0	11.7	25.9	kN
stemvol	1.19	0.54	2.34	m^3
piece	2.01	1.00	3.00	n
hord	707	367	884	m
verd	221	112	272	m

[1]see Table 3 for definition of variables.

Analysis of Effects

Results from the covariance analysis (Table 6) demonstrate the importance of the different variables related to total variability. Almost half of the variation (R^2=0.493) in the productivity of the K-Max can be explained through the variables stemvol, hord, TREAT, PILOT and CHOK. The pilot's K-Max experience affects productivity, explaining about 38% of the total variance. The next most important effects are the silvicultural treatment and whether or not the chokers were returned to the harvest area.

Table 6. Effects influencing helicopter productivity, MANOVA results.

Source of variation	DF	SSQ	SSQ(%)	F-value	Pillai's trace F-value
$stemvol^{0.4}$	1	1.25	2.6	30.9	17.8
hord	1	0.39	0.8	9.7	7.9
TREAT	1	1.71	3.6	42.4	15.8
PILOT	1	18.56	38.6	459	195
CHOK	1	1.76	3.7	43.7	22.4
residuals	604	24.39	50.7		
		48.06	100		

Productivity Model

The statistical analyses resulted in the productivity model shown in Equation (2). All model parameters were significant at a = 0.01. The significance of the regressions may be due in part to the large error degrees of freedom and due to possible autocorrelation among some of the replicates since only two harvesting sites (one for each silvicutural treatment) and two helicopter pilots were studied. Pillai's trace measures the trade-off between loss of degrees of freedom and increase in variance explained across all dependent variables in MANOVA models. Pillai's trace results for the model (Table 6) indicate these variables remain significant. In addition, the relationship in Equation 2 are reasonable in terms of both magnitude and direction.

$$PROD_{k\,max} = 0.442 + 0.2546 * stemvol^{0.4} - 0.0004 * hord \quad (2)$$

Where:

$PROD_{kmax}$	=	Productivity of the K-Max helicopter per productive system hour without delays (m^3/min)
stemvol	=	Average stem volume per cycle (m^3)
hord	=	Horizontal distance from stump to landing (m)
TREAT	=	Silvicultural system: (0) femel cut and (1) clear-cut
PILOT	=	Pilot's K-Max experience: (0) inexperienced Pilot and (1) experienced pilot
CHOK	=	Chokers returned: (0) no und (1) yes

The productivity of the K-Max helicopter is a function of the stem volume and silvicultural system (Figure 1). The graphic shown is based on an experienced pilot, a horizontal flight distance of 400 m and no chokers being returned to the site. The productivity of the clear-cut extraction is 0.20 m^3/min greater than that of the femel-cut operation. Considering an average stem volume of 1.5 m^3 this means a productivity increase of 21%.

While Dykstra [3] could not find any difference between extraction from small and large harvest areas, Krag and Clark [15] showed a decrease in productivity as the harvest area decreased. Relative to the clear-cuts, the productivity when harvesting small femel-cuts or single-tree extraction was reduced by 6% and 13% respectively. However, Heinimann and Caminada [12] indicate that typical conditions for small patch-cuts are different in Europe than in North America. Sloan *et al*. [18] studied timber extraction with a K-Max in shelterwood and found a very low productivity, which was linked back to the lack of experience of the pilot. Both pilots in that study were experienced in timber extraction, but were neophytes flying the K-Max.

In this study the inexperienced pilot had helicopter timber extraction experience, but it was their first time flying the K-Max with the exception of his flight training (30 hours flight time). The experienced pilot had 22,000 hours of flight time on the K-Max.

The productivity difference was likely related to the experience of the pilot (Figure 2). The basis is a femel-cut operation with an average horizontal extraction distance of 400 m. The productivity for the experienced pilot is 0.37 m^3/min or 63% higher. This is a very significant productivity difference, especially considering that both pilots had experience in timber extraction with helicopters. Stampfer [20] was able to show similar results for cable yarder operators. These findings are further evidence that indicates that technology changes can result in learning-curve effects even with experienced operators.

The impact of the pilot experience on the productivity is especially a concern when attempting to make comparisons between harvesting systems. Stampfer [20] recommended that for the comparison of productivity studies the minimum experience a crew should have is one year.

CONCLUSIONS

The goal of this paper was to compare the productivity of timber extraction using the K-Max helicopter under two different conditions of silvicultural treatment and pilot experience. For this purpose, a productivity model was developed based on empirical data. The productivity of this helicopter extraction is dependant on average stem volume and stump to landing horizontal distance. Also the flight cycles that returned the chokers to the stand had a significant influence on the productivity. Productivity was significantly different for the two harvest blocks (femel-cut and clearcut) and for the two pilots. These latter differences are likely attributable to the silviculture treatment and experience of the pilot, respectively.

The average helicopter cycle was about 3 min, which compares favorably with results established in Heinimann and Caminada [12]. When chokers need to be returned to the stand the cycle is increased by about 20-25%. In comparison to the 27 kN maximum payload capability of the K-Max, the average payload of 20 kN indicates a 74% utilization of capacity. Typical payload utilization for helicopters is 60 to 80%.

Extraction productivity was significantly different in the clear-cut and femmel-cut sites. An absolute increase in productivity of 0.20 m^3/min in clear-cut versus femel-cut was established, which is an increase of 21% at an average piece size of 1.5 m^3. Krag and Clark [15] had shown productivity increases in clear-cuts relative to patch-cuts

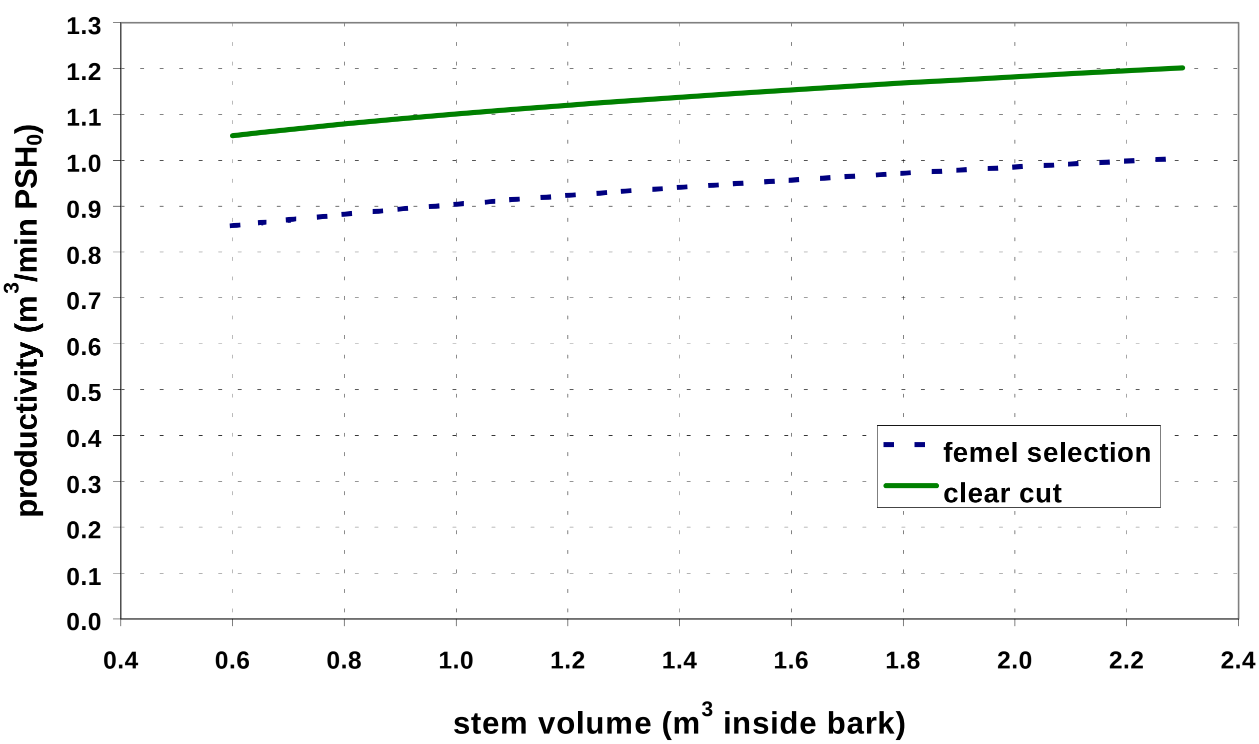

Figure 1. System productivity (m^3/min) for the K-Max Helicopter as a function of the average stem volume and silvicultural system (experienced pilot, horizontal distance 400 m).

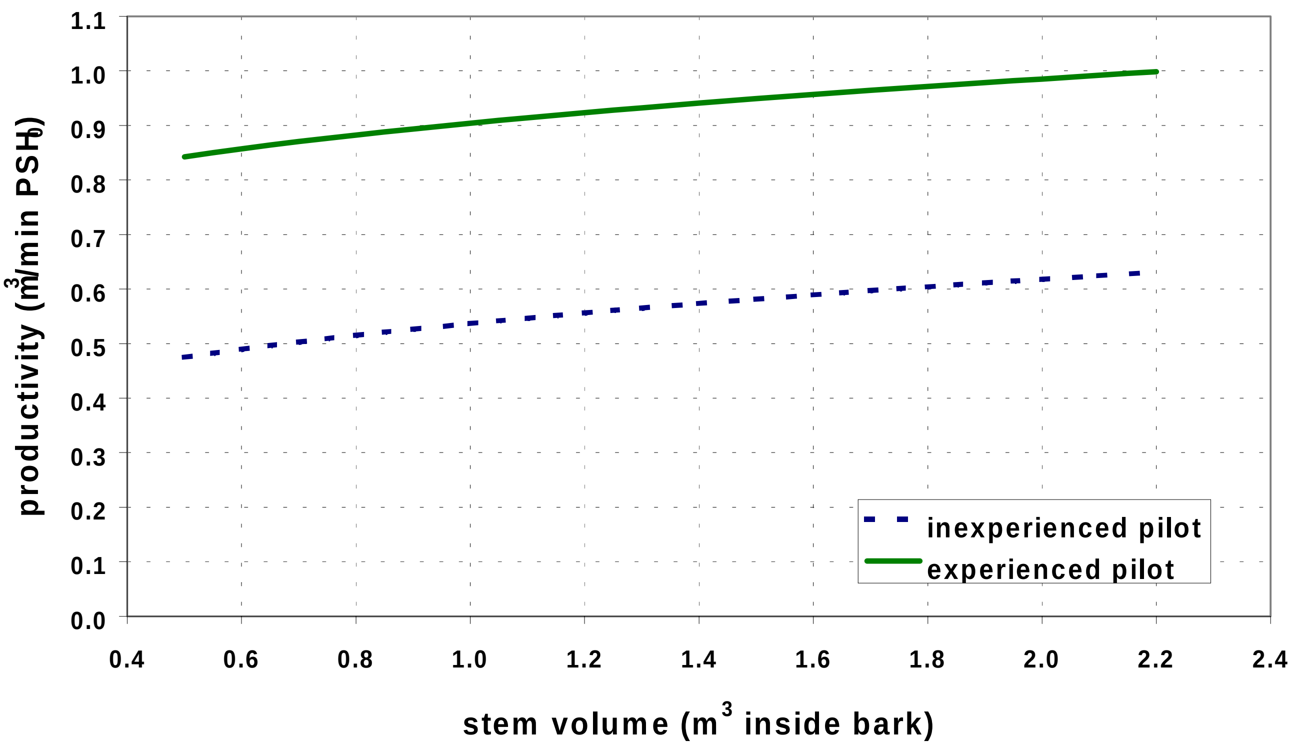

Figure 2. System productivity (m^3/min) for the K-Max Helicopter K-Max as a function of average stem volume and pilot experience (femel cut, horizontal distance of 400 m).

of up to 11%. While no significant differences were established between larger and smaller clear-cuts in a study completed by Dykstra [3], it is important to note that the term 'small clear-cuts' has a different meaning in Europe than it has in North America.

There was also a significantly higher productivity demonstrated by the pilot with 22,000 K-Max flight hours and the inexperienced pilot. The productivity difference in absolute terms is 0.37 m^3/min, which in relative terms for an average stem size of 1.5 m^3 is 63%. Stampfer [20] showed that learning-curve effects for yarder operators disappears after one year. Pilots may show a similar trend. The relatively large pilot productivity difference should be considered when making system comparisons.

It would be desirable to replicate the kind of study carried out here with a larger number of pilots with a broader range of experience to verify the preliminary findings and determine at what level the effect of differences in experience tapers off and site/ treatment differences become more important variables. Given that modern helicopters allow continuous data capture of all operational parameters, the cost of such learning-curve research may be greatly reduced.

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